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SHAFT SINKING UNDER DIFFICULTIES AT DORCHESTER BAY TUNNEL, BOSTON, MASS.

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The body of this paper will be devoted to a detail of actual experience in shaft building under difficult circumstances, but that the existing local conditions may be better understood, we will commence by a short general sketch of the work with which these shafts are immediately connected.

The system of improved sewerage, now being carried out by the City of Boston, is too extensive and complex in its ramifications to be treated of in this paper; we will therefore begin at the Pumping Station on Old Harbor Point, the terminus of the low-grade intercepting sewers.

The sewage, in passing from the pumping station to the point of final delivery, on Moon Island, must cross under Dorchester Bay, a navigable arm of Boston Harbor, about two miles wide from shore to shore, and to this end an inverted syphon or submarine tunnel becomes necessary.

After an examination into the geological formation of this region, it was determined to locate the horizontal portion of the syphon at a sufficient depth below the surface of the water to be entirely contained *within* the rock which was found to underlie the bay. This determination fixed the average invert grade of the finished tunnel about 142 feet below mean low tide, or Boston City datum. The ship channel is only 18 feet deep at low water, but the material overlying the rock was mud, clay, sand and gravel, so irregular in its deposit, and so unreliable in its general character, that tunnelling through it was an impossibility with the Atlantic ocean practically overhead.

The rock to be passed through belongs to the clay-slates, with, so far, infrequent strata of very hard conglomerates. But at some remote period this ancient sea floor, in taking its present trough-like shape, has been subjected to enormous pressures, much disturbing the original stratification, breaking the beds in many places and leaving them tilted at high angles to the horizon. The numerous faults consequent on this action, have been generally well filled again by injected material, but crevices, fortunately slight in extent, are frequent, which communicate more or less directly with a water-bearing stratum of sand, gravel and boulders, which seems to be continuous over the surface of the rock. Wherever cut by the tunnel section, these seams allow a greater or less percolation of sea water into the workings below, amounting at this date (July, 1881), to 1½ millions of gallons daily, which can, of course, only be removed by constant pumping; the length of tunnel now excavated being 4 600 feet.

Plate XLIV, is a general profile of the tunnel, and shows the rock dipping rapidly from east to west. To meet this rock at as high an elevation as possible, the western, or inlet shaft, was pushed out about 1 400 feet from the Boston shore of the bay, and connection made between it and the pumping station, by a high-grade tank sewer, founded

upon an embankment, and protected by rip-rap and a sea-wall. Four pumps, of a capacity of 25 million gallons each, daily, will raise the sewage a height of about 43 feet, and deliver it into this tank-sewer, the invert grade of which is $15\frac{5}{10}$ feet above city datum. This tank is double, each section being 8 feet wide by 16 feet high, and the interior is provided with a series of dams, which will intercept any heavy material that may pass through the screens provided at the entrance to the pump well. Either compartment of the tank can be shut off by gates, and cleaned, and by means of stop planks, the velocity head can be greatly increased, and the tank sewer used to flush out the tunnel, sea water being pumped into the tank for this purpose.

At the Inlet Shaft, the bottom of which is 142 feet below datum, the tunnel commences, and runs in a south-eastwardly direction for a distance of 6 090 feet, to the centre of the East Shaft, the bottom of which is 144 feet below datum; at this latter point the tunnel grade commences to rise at the rate of one foot vertical in six feet horizontal, and continues at this grade for a further horizontal distance of 903 feet, until the tunnel pierces the surface of the ground on Squantum Head, which forms the eastern side of Dorchester Bay.

At the eastern terminus of the tunnel, the invert grade is $14\frac{4}{10}$ feet above datum, and from this point the sewer is continued in an open cut across Squantum Head, and then on an embankment over the shoal water lying between the Head and Moon Island, to the collecting basin on the island, from which basin the sewage is emptied into the bay at each ebb tide by an appropriate system of gates and outfall chambers. The point of discharge is four and one-half miles in a direct line from the State House in Boston.

Dimension of Tunnel and Shafts.—The tunnel and the shafts are circular in section, with a finished inside diameter of 7 feet 6 inches. The tunnel and shaft excavation, as at first taken out, is as near as may be, 9 feet 6 inches in diameter, provision being thus made for a final lining of brick-work throughout, 12 inches thick, for the purpose of reducing friction. This brick-work is intended to be water-tight, and at the inlet shaft, gates and an outfall sewer will be built, leading from the tank sewer, so that the sewage can be discharged directly into the bay at this point, and the tunnel pumped out, examined and cleansed, when such a proceeding may be deemed necessary. To intercept any solid matter that may pass into the tunnel, a sump, 6 feet deep is provided at

the bottom of the East Shaft, and consequently at the foot of the Incline, from which sump the material may be removed by dredging through the shaft. The Middle Shaft, shown on the profile, is simply for working purposes, and may be finally filled up.

BULKHEADS ABOUT SHAFTS.—As all the shafts are located in water, from 3 feet to 15 feet in depth, depending upon the state of the tide, bulkheads were necessary, from which to commence operations, and to protect the mouth of the shaft from damage by storm, ice, passing vessels, &c. As shown at Figs. 1 and 2, Plate XLV, these bulkheads consisted substantially of a box 20 feet square inside, formed of oak piles driven 2½ feet apart from centres, and capped by 12″ x 12″ hard-pine sticks, framed at the corners, and drift-bolted to the head of each pile. These caps were further secured at the corners by 12″ x 12″ angle-braces, dovetailed into them. The box was lined inside by 4-inches tongued and grooved sheet-piling, driven to hard bottom, and well spiked to four lines of 4″ x 10″ inside wale pieces. Outside of the piles were two sets of 12″ x 12″ hard pine timbers, spaced four feet apart vertically, and bolted to the piles by 1¼-inch bolts, and tied at the corners of each set by 2″ diagonal rods. The top of this bulkhead was 18 feet above mean low tide, the average rise and fall of tide being ten feet After the iron cylinder had been started within this box, the spaee surrounding the cylinder was compactly filled with puddle clay.

THE IRON CYLINDERS.—To quote from the specifications, "iron cyl-"inders were to be sunk to a depth sufficient to give them a firm bearing, "to ensure the exclusion of tide-water, and to pass through ground "otherwise difficult to excavate." These cylinders are 9 feet 6 inches inside diameter, 1¾ inches thick, and cast in solid sections 5 feet long. The flanges are 5¾ inches wide over all, 2 inches thick, and faced true for a width of 4⅜ inches in from the exterior edge. A groove ½ inch wide, and 1⅜ inches deep, was left between any two abutting cylinders, on the inside, to be caulked with lead if found necessary. The sections were connected by thirty turned bolts, 1⅛ inches diameter, in each joint, and the bottom section in each shaft was provided with a cutting edge, 12 inches deep. The weight of each section was five tons, or one ton to the lineal foot of iron cylinder. The joints were made water tight, by first painting them with thick red lead, and then passing four turns of cotton wicking, dipped in the paint, around the outside line of the bolt holes;

grummets of the same wicking, dipped in paint, were put under the heads and nuts of all the connecting bolts. These joints proved perfectly water tight.

SINKING THE CYLINDERS.—After the bulkheads were completed, pile wharves had to be built adjoining them, upon which to place the hoisting engines, boilers, coal bins, fresh water tanks, &c. To handle the five ton cylinder sections, four stout shear-poles were erected, resting on the corners of the bulkhead, and meeting at the top, over the centre of the proposed shaft, where the ends were secured by rope lashing (Fig. 1, Plate XLV). A hoisting tackle of two triple sheaved "masting blocks," and 4-inch manilla rope was suspended from the apex of these shears. Owing to delay in obtaining the proper kind of clay filling, and to avoid the increased friction as well, the first five cylinder sections in each shaft, were put in place by means of friction clamps, shown at Fig. 2, Plate XLV. These clamps were made of two compound beams of hard pine timber, thrown across the bulkhead, one each side of the cylinder. Each beam was composed of three 12″ x 20″ sticks, the inner one of each beam being carefully fitted to the outside of the cylinder; to increase the friction, four vertical timbers, 12″ x 12″ and four feet long, were bolted to the inside of the beams, as shown on the plan. The clamps were drawn together and made to hold any object between them, by tightening up the nuts on two 2½-inch iron rods that passed through the beams, one each side of the cylinder section. We should here remark, that owing to its resinous nature, hard pine is not well adapted for use in that part of the beam touching the cylinder, white pine is much better, but in our case could not be obtained in time of the required dimensions. The method of operating these friction clamps, was as follows: No. 1 section was first lowered down between the beams, and clamped fast. No. 2 section was next lowered down upon No. 1, the joint made, and the connecting bolts put in and screwed up; with the hoisting tackle still attached to the last section as a "preventer," the two sections were allowed to slip down between the clamp beams in a series of short jumps, by carefully slackening and then tightening the nuts on the clamp rods with a long wrench. A little practice enabled the workmen to keep the mass under perfect control. When No. 2 section occupied the place in the clamps previously held by No, 1, the nuts were screwed up tight, the tackle cast off, and the 3d section bolted on, and lowered in like manner. This process was repeated until the cutting

edge on the first section had reached hard bottom, when the clamps were loosened, and thereafter utilized as guides.

HANDLING THE MATERIAL EXCAVATED.—Before the permanent hoisting cages were put in place, the material excavated in sinking the shafts, and in driving a considerable portion of the tunnel as well, was handled by an arrangement shown at Fig. 1, Plate XLV. This was simply an out-haul, working through a single block lashed to the head of a mast planted in the bulkhead ; this mast leaned outward at the top—over the side of the bulkhead. In using this arrangement, the bucket is hoisted a distance above the shaft, fixed by experiment—the out-haul being hooked on to the bucket just as it reaches the mouth of the shaft—and the slack hauled in as the bucket ascends, when the bucket stops, the end of the out-haul is made fast to a cleat on the mast, and the bucket in descending will pass through a curve regulated by the length of the outhaul, until it hangs vertically from the top of the mast, and over the sides of the bulkhead, where it can be dumped. A reversal of this process will bring the bucket again to the top of the shaft, where the out-haul is unhooked, and the bucket lowered to the bottom for refilling.

SINKING WEST OR INLET SHAFT.—All of the foregoing description applies to the three shafts, generally ; we will now confine our remarks to the west shaft, where the depth of the material overlying the rock was greatest, and the difficulty of sinking in like degree increased.

Previous to the letting of the contract, test borings had been made over the line of the tunnel by the City of Boston, and the results exhibited.

Owing to the great expense of so doing, these borings in no place penetrated the rock proper, and, therefore, they failed to give any certain indication of the presence, at each shaft at least, of a stratum of boulders, sand and gravel, lying immediately on the rock, and containing a large body of water. At this west shaft especially, the worst feature shown by the borings, was a sandy clay. The tunnel grade had to be finally lowered 8½ feet below contract grade, to meet this changed condition of affairs.

The material was actually deposited at the west shaft, in about the following sequence : Commencing at the top, mud 3 feet, pure sand 5 feet, and then strata of varying thicknesses of pure tough clay—clay with thin seams of fine sand, and clay intimately mixed with sand. Above

the surface of the solid rock, and meeting the clay and sand deposits, was a stratum 14 feet thick, of large boulders, gravel and very sharp sand, and in this lowermost stratum water to the amount of about 17 000 gallons per hour was found. This water was salt and seemingly in direct communication with the bay above.

In the sand seams struck before the boulder stratum was tapped, brackish water, in maximum quantity not exceeding 200 gallons per hour, was found, but these seams generally drained out and gave little or no trouble. The surface of the solid rock was finally located at the west shaft 123 feet below city datum.

Seven cylinder sections, making 35 lineal feet of iron shafting, were sunk without much trouble, but at this point the frictional resistance of the clay was sufficient to prevent any further sinking of the iron lining by its own weight merely, although the material was excavated below the cutting edge. At this time the surface water was entirely excluded, and the shaft was dry. A dead weight of at first 50 tons was now applied, as follows: On top of the flanges forming the second cylinder joint, or 10 feet from the bottom of the shaft, a platform was built, made of four 12" x 12" hard pine sticks, laid in pairs, parallel to each other, leaving a 6-inch space between the two sticks in each pair, and a space of 4 feet between the pairs. These four sticks were accurately fitted to the inside of the cylinder, with as great a bearing surface on the flanges as was possible, holes being made in them for the heads of the cylinder bolts. Two struts, 12" x 12" and 4 feet long, were let in between the pairs, and at right angles to them, so as to leave a central opening 4 feet square, opposite the ends of these struts and between the sticks forming the pairs, four wedges were now driven, and the whole structure thus secured in the cylinder. A shaft 4 feet square inside, made of 4-inch plank, on end, and internally braced, was next erected on this platform, and the space outside this box shaft well packed with iron refuse from a puddling furnace. As the cylinder descended, and the friction became greater, this dead weight was increased to a little over 100 tons by putting in a second platform and box higher up in the shaft. Eight heavy screw-jacks were also applied in addition to this weight, on the top flange of the cylinder, reacting against trussed beams, secured by chains to the bulkhead piles.

When the cutting edge of the shaft lining had reached a point 57 feet below city datum, the area of surface then exposed to possible friction

being over 1 800 square feet, all our combined appliances failed to push it any further, and the use of the specified solid iron cylinders had to be discontinued.

Continuation of the Shaft to Rock.—No plan whatever of continuing the shaft after the cylinders were pushed as far as was possible, being specified, the contractor was at liberty to adopt any method that might seem to him most fitting. From the data before him timber was deemed sufficient, and a timber lining was adopted; the shaft was dry, all water from above excluded, and nothing but clay indicated below him until the rock was reached. Of the wisdom of this decision we will here say nothing, considering that all the known data was derived from deep borings—which more often lead to trouble than exhibit the actual condition of affairs.

The timber shaft was 10 feet square inside, and built of 12″ x 12″ spruce timber, laid skin to skin. As shown at Fig. 4, Plate XLVI., the sticks were cut and laid in alternate lengths of 10 feet and 12 feet, locking over each other at the corners, and to prevent the shorter timbers from being forced inward they abutted against cleats 4″ x 10″ x 16″ well spiked to the long sticks. They were further held in place by the bracing described further on.

The first timber course laid was only 8 feet 10 inches square inside, each succeeding course stepping back 2 inches, until the full dimension of 10 feet square was reached. This was done to give the cutting edge of the iron cylinders a bearing on top of the timber work, at least in the centre of the four sides. Between the top course of the timber work and the iron, a space four inches wide was left in which 4-inch sheet piling was driven out horizontally into the clay and the corners outside the circle thus closed.

The greatest difficulty to be dealt with from the start, and the chief objection against such a compound shaft of iron and wood, was that of properly connecting the two. The corners of a square wooden shaft are the points best adapted for the location of any suspending members, but in our case these corners were outside the cylinder, and consequently, not available. At first four of the cylinder bolts were removed from the bottom joint in the cylinder and replaced by four 1½-inch rods, with nuts at the top and lipped plates, catching under the bottom of the second timber course, and secured by 1-inch rag bolts to this course; below this the hanging was continued by vertical plank spiked to the timbers.

As the shaft increased in length, these $1\frac{1}{8}$-inch rods were supplemented by four rods 2 inches in diameter, suspended opposite the centre of each side of the shaft, from heavy iron castings, bolted on top of the second cylinder joint. An iron plate 6" x $\frac{3}{4}$" and 8 feet long was bolted by eight 1-inch bolts, to the middle of each side, and at the top of this plate was an "L" shaped head 8" x $1\frac{1}{2}$", through which the 2-inch rod passed, and was there secured by a nut.

This timber shaft was sunk with very little trouble to a point 95 feet below datum, with a maximum quantity of water from the thin sand seams not exceeding 200 gallons per hour. But at the point first mentioned, water suddenly burst in from below at the rate of about 10 000 gallons per hour, driving out the workmen and rapidly filling the shaft, to low tide mark. A steam pump was at once put in place and the shaft again emptied. An examination showed that, while the source was at some point below the bottom of the shaft, the water had in places forced its way up behind the timbering and was entering the shaft in jets through every possible crevice. And what was worse, the main stream was undermining the sides at the bottom, and the jets above were washing the fine sand inside, leaving voids outside the shaft lining. The sides were at once caulked, and the water driven to the bottom, and the 8" x 8" bracing, only partly in place, was completed to within four feet of the bottom. The iron cylinder soon commenced to sink, very slowly, showing that the ground surrounding the shaft was in motion clear to the surface. The bulkhead and the adjoining portion of the machinery wharf sank with the cylinder.

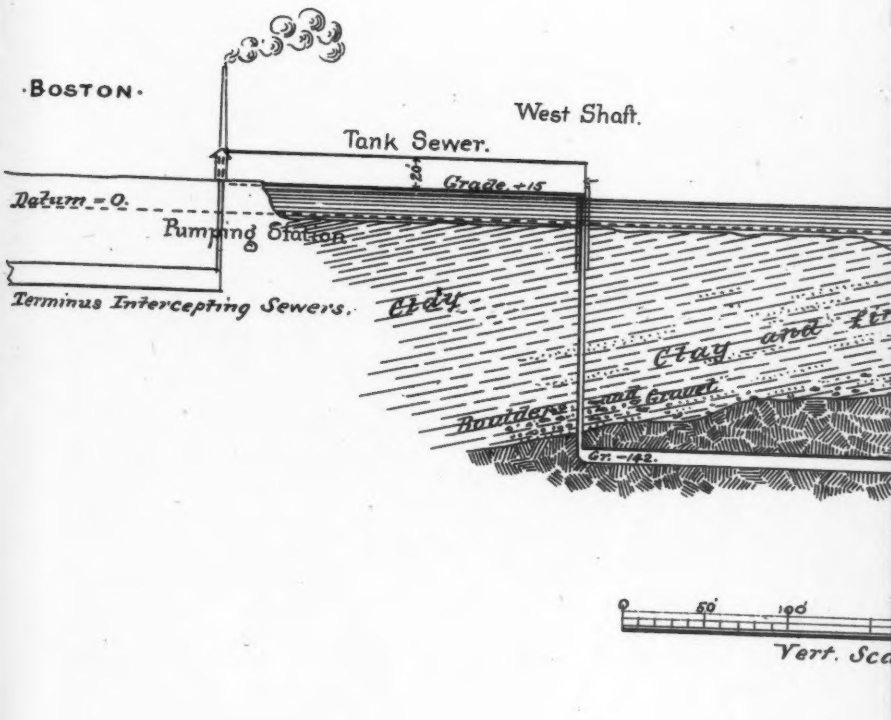
The bottom was now a sandy clay, but firm, the water passing to the southwest corner of the shaft as soon as we commenced re-sinking. The material on the east and north sides seemed to drain out and remained quite firm, while on the other sides it soon became very soft, in places semi-fluid. This action increased the strain on the soft sides and tended to throw the timber courses out of the horizontal, the west side sinking more rapidly than the east. As long as the bottom remained firm this inequality of settlement was arrested by "rakers" and "props." All timbering on the soft sides could only be put in place by first carefully poling those sides, but surplus material would escape inside, and increase the pressures. All went well enough under the circumstances until we reached grade—104,

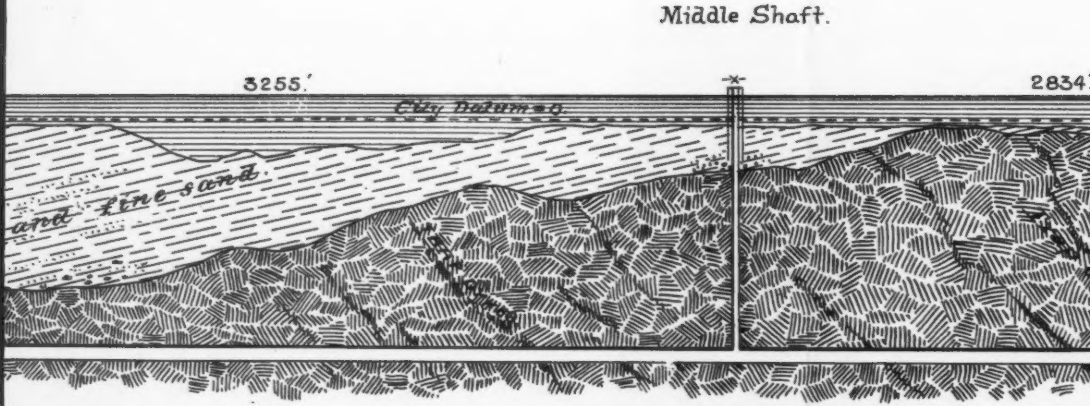
where we suddenly struck a stratum of soft, almost dough-like clay, which we afterwards found was the direct covering of the water bearing stratum of boulders, &c. Into his soft material our rakers, props, &c., easily sank and became useless as supports, and thereby the strain upon the rods and hanging members on the soft sides was enormously increased, and the west and south 2-inch rods both broke, just above the lower nuts. The immediate cause being the slight bending of the "L" shaped heads of the straps, thus acting as levers on the nuts and ends of the rods. Some of the plank lacing also commenced to give way, and being behind the corner bracing could not be repaired.

Two steam pumps, a No. 8 Blake, and a No. 10 Knowles, were at this time located in the timber portion of the shaft, supported upon platforms, the discharge and steam pipes were clamped to both the iron cylinder and to the sides of the wooden shaft. As soon as the 2-inch rods broke, severing the connection on those sides between the iron and the wood, the lower portion began to settle more rapidly than the cylinder. The effect of this was to break the bottom elbow on the discharge column of our large pump, flooding the lower portion of the shaft to the height of the suction on our reserve pump, the No. 8, at a very critical period. This damage was repaired as soon as possible, and a re-occurrence of the accident prevented by slinging both of our pumps by wire rope to the iron cylinder, and wedging up between pump and platform as the wooden shaft settled.

On sounding through the soft stratum hard bottom was found about 7 feet below the then bottom of the shaft, and as this was very near the point which the boring indicated as rock, we continued sinking. After some tedious and dangerous work, and much trouble and delay from our pumps, which, as is usually the case, were always breaking down just when most needed, we reached the hard bottom only to find it was not ledge rock, but the top of a boulder stratum, of then unknown depth, and the source from whence came all our water, now much increased in quantity. The sand in this deposit was unusually sharp, and would scour through a brass pump lining ¼ inch thick in less than three days, causing further and dangerous delays.

We attempted to sound the boulder stratum by driving iron bars,


·BOSTON·
West Shaft.
Tank Sewer.
Grade +15
Datum = 0.
Pumping Station
Terminus Intercepting Sewers.
Clay
Clay and
Boulders and Gravel
Gr. -142.
0
50
100
Vert. Sca



Profile Dorchester Bay Tunnel.

Hor. Scale. 600 Ft = 1 inch
Vert. " 100 Ft = 1 "

Vert. Scale.

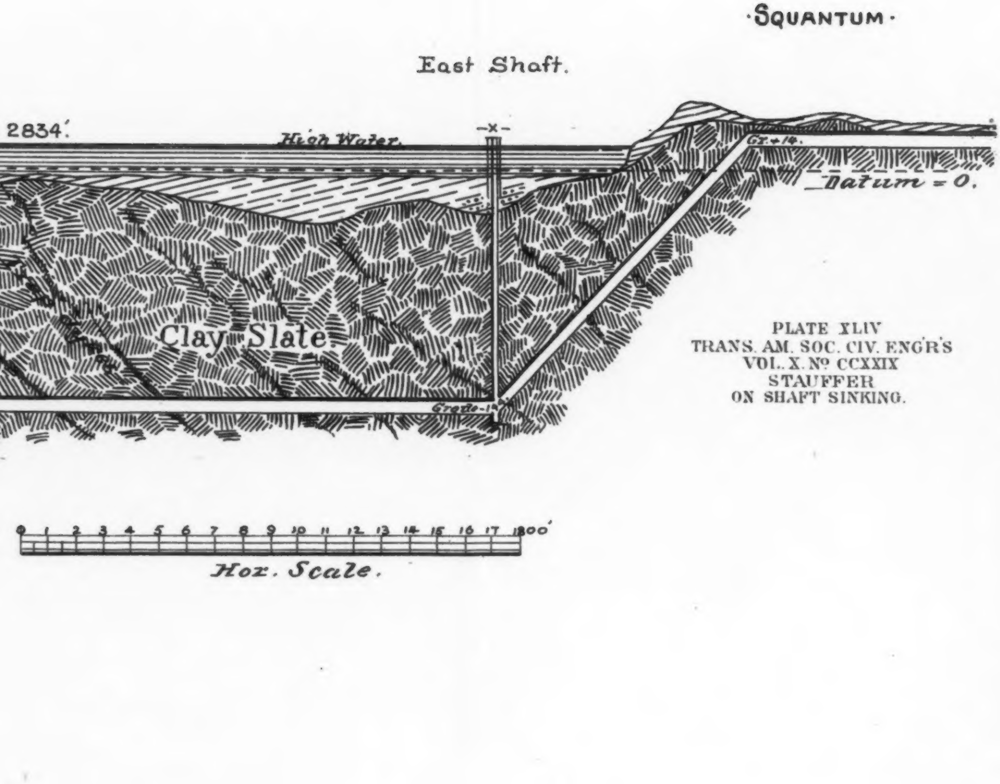


PLATE XLIV
TRANS. AM. SOC. CIV. ENG'R'S
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ON SHAFT SINKING.

but failed to get any satisfactory results until we started an artesian boring in a 5-inch pipe, and finally drilled some 8 feet into the rock establishing its actual depth and character.

At this time the bottom portion of our timber shaft was in very bad shape, many timbers broken, the hanging appliances a failure, and the courses very much out of the horizontal. To continue sinking under these conditions was to invite certain disaster. On the other hand, if we stopped sinking, the only alternative to building a new shaft in another location, was the somewhat desperate one of attempting to re-timber the lower 36 feet of the shaft in the face of the moving ground and the consequent pressures. We determined to re-timber without waiting for the ground to settle.

The upper 23 feet of the timber work was still in good condition, the courses almost level, and the lacing intact. This portion we concluded to leave in, but it had first of all to be securely connected with the iron cylinders, and upon the integrity of this connection all success depended. Iron rods were abandoned in our plans for several reasons, among these the difficulty of attachment, and the fact that in one place, certain obstructions in the shaft prevented a fair lead. Iron wire cables were substituted for rods. Four cables, made by Roebling Bros., were at first used, each cable 6¾ inches in circumference and 22½ feet long from bearing to bearing of the eyes and thimbles spliced into each end. The upper eye was made heart shaped, so that the lashing to be used would not ride and cut under the strain to be put upon it, the lower eye was made to take a 2-inch iron pin, and the splices on each cable were further secured by broad iron clamps bolted over them. On top of the first or lowermost cylinder joint, two hard pine timbers 12" x 20" were placed, after having first been accurately fitted to the inside of the cylinder; holes were bored vertically through these sticks, just clearing the cylinder flanges, and passing through these holes, secured above by nuts and 12-inch cast-iron washers, were four eye-bolts made of 2½-inch round iron; two struts were driven between the 12" x 20" timbers, to prevent motion.

The lower connection for the cables was more troublesome. At the point selected, two hard pine beams 12" x 20" and 12 feet long were inserted in the shaft horizontally, the ends extending out under the sides. These two beams ran in the same direction as the shorter

beams in the cylinder, and were vertically under them. Around each of the 12 feet beams, and directly under the eye-bolts, were four iron stirrups each 6 inches by 1 inch, with two eyes in each stirrup just over the centre of the beam.

Between these eyes the lower end of the cable was inserted and secured by a 2-inch iron pin. The upper eye of each cable was now lashed to its proper eye-bolt by steel wire rope set taut by a purchase connected with the hoisting engine.

The connection being now completed between the iron cylinder and the 26 feet of wood work to be left in place, the workmen commenced replacing the old and crippled timbers, below the hanging beams, with new and level courses—in other words, rebuilding the lower portion of the shaft. As shown on Fig. 1, plate XLVI., a system of timber hanging was at first attempted with 4-inch plank, which plank acted at the same time as struts for the corner braces. This system was soon abandoned. It was all right theoretically, and had it been as easy of application in the shaft as on paper, would no doubt have answered admirably, but in practice it was found impossible, under the circumstances, to keep the inside faces of the timbers sufficiently true to plank against in the manner intended. The same principle was, however, retained by using iron straps 3" x ⅜", and four feet long, spiked with 10-inch wrought iron spikes to the timber. These straps were applied in the corners behind the braces, in such manner that each new stick was suspended by two of these straps as soon as it was in place—four feet of the bottom of the shaft was necessarily left unbraced for convenience in working.

A second set of hanging timbers was put in twenty feet below the first,and entirely independent of that set (Fig. 1, Plate XLVI.). In this set each hanging beam was made up of two 12" x 12" timbers, placed one on top of the other ; the upper one was 12 feet long and passed through the sides of the shaft, the lower one was 10 feet long, and acted as a strut as well. Two 2-inch iron rods, about 10 feet long, each provided with an eye for a 2-inch pin above and a nut below, secured the lower end of each secondary cable to the beams. These rods, in pairs, carried the compound beams between them, the lower ends of each pair of rods passing through a stirrup plate 8" x 1½" under the bottom stick, and there secured by nuts. These cables were galvan-

ized iron wire $4\frac{1}{2}$-inches in circumference. They were lashed at the upper end to four 2-inch eye-bolts, which passed through castings bolted on to the second cylinder joint.

This re-timbering was slow and dangerous work, and the greatest care possible in poling could not prevent the escape of some of the outside material into the shaft, the voids thus created, though comparatively slight, kept the ground in constant motion, the settlement being apparent clear to the surface. The first wire cables soon became as taut as harp strings. At first the greatest weight was thrown on the western pair of cables, leaving the east cables comparatively slack ; the strain on the cables was equalized by setting up rakers, extending from the heavy west side to the east end of the main hanging beams. The total settlement of the iron cylinder after the timbering was commenced was just five feet.

The timber shaft was in the above manner successfully carried down to the solid rock, the shaft continued 20 feet into the rock, and the tunnel commenced. About five months after the completion of the timber work the brick lining was commenced. To conform to required lines it was necessary to cut entirely through some of the shaft timbers, and at the centre we found the clay outside generally drained, and in good condition. In the time specified above, the brick work was completed with but little trouble from any motion in the adjoining ground, caution however, was required, and the work was slowly and carefully done.

Pumping out Shafts.—The west and the east shafts were at different times filled with water ; the first was lost by a failure of our boilers, the other by suddenly uncovering an unusually large seam in the rock, through which more water entered the tunnel than could be handled with safety by the two pumps then in place—one of the pumps broke down under the hard work, and the tunnel and shaft filled up. All of our shafts were too small in diameter, when their depth and the quantity of water to be raised through them is considered. This want of shaft room made our method of regaining them somewhat peculiar, and we will relate our experience.

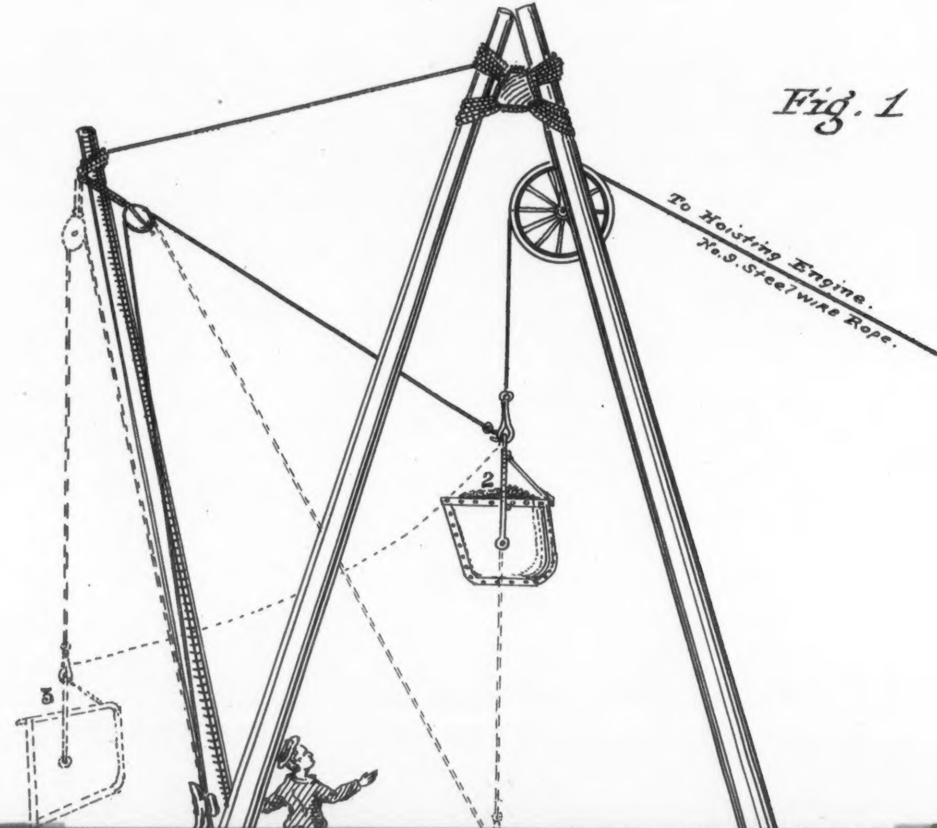
When the eastern shaft was flooded the amount of water to be pumped against was 18 000 gallons per hour, constantly flowing into the tunnel. To handle this quantity of water with safety, under the working conditions, would require a pump of the capacity of a No. 11

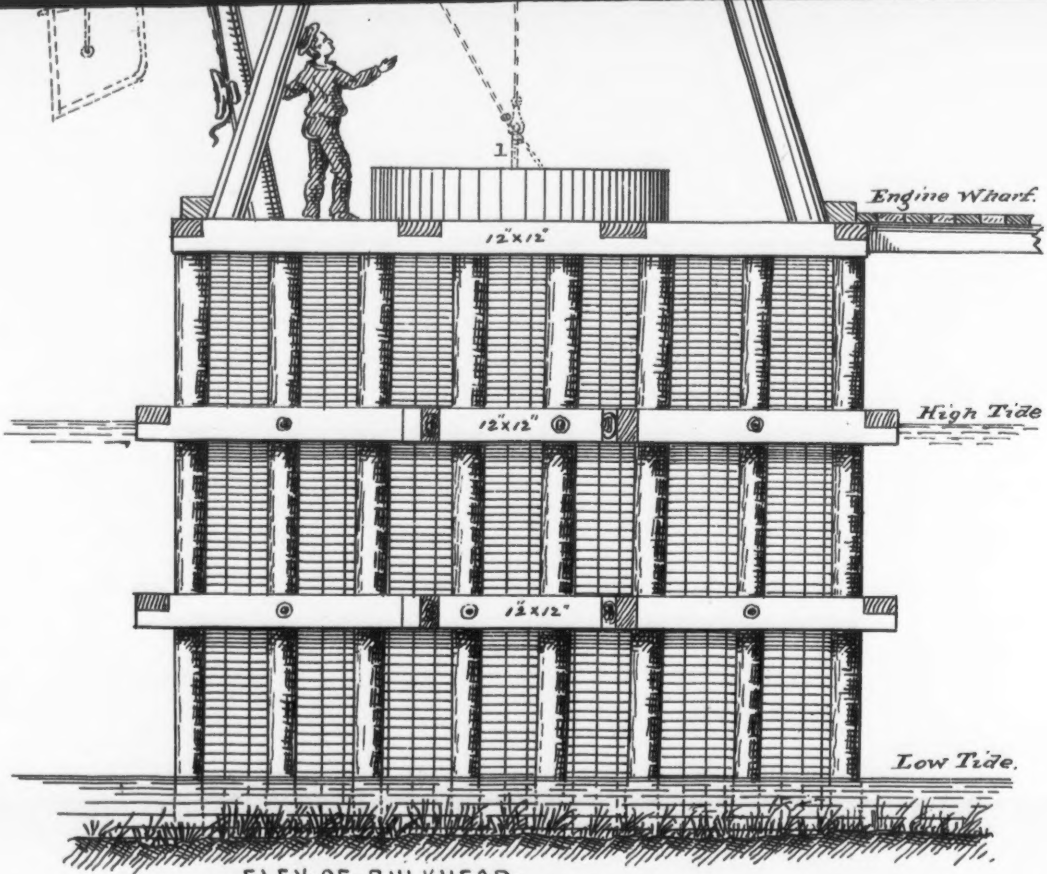
Knowles, which measures 9 feet over all, and would require an additional 2½ feet of room at the water end to allow packing, etc. It can be readily seen that such a pump could not be located horizontally, within the iron cylinders, which, as before mentioned, were only 9 feet 6 inches in diameter, a space further reduced by the flanges to 8 feet 10 inches.

To overcome this difficulty we had a special pump built by the Knowles Company, of the bucket and plunger type, double-acting, and working vertically. This pump had a 14-inches steam cylinder, 12-inches plunger, 17-inches bucket, and 24-inches stroke ; its capacity was 11¾ gallons per stroke. (The steam cylinder proved too small for the work to be done, it should have been 16 inches.) The pump was 12 feet long over all, and 3 feet in diameter at the widest part, and with 20 feet of thin wrought-iron suction pipe 10 inches in diameter attached, weighed 7 000 pounds. The steam pipe was 2 inches, the exhaust 3 inches, and the discharge column was 6-inch galvanized-iron spiral pipe in 16 feet lengths, connected by flanges and six ¾-inch bolts.

On account of its shape this pump was used without platforms built in the shaft. Two heavy beams were thrown across the top of the shaft cylinders, and from these the pump was suspended by a purchase made up of two large triple-sheaved masting blocks, and six parts of 4-inch Manilla rope, connection with the pump being made by a strong eye-bolt screwed into the head of the steam cylinder, and by chain slings passing down to the water barrel of the pump. The running end of this purchase passed from the lower block up to a large single block lashed to the top of the four-legged shears, shown at Fig. 1, Plate XLV., and from there down to the wharf, and through a snatch-block to the drum of the hoisting engine. The 6-inch discharge column, and the 2-inch steam pipe, were clamped to separate steel wire ropes, that were secured to the pump below, and thence passed over sheaves lashed to the shears near the top, but as far apart as possible ; from these sheaves each rope went through a snatch-block on the wharf, and then to large cleats, all so arranged that each rope could be paid out steadily, and independently, as the pump was lowered. The exhaust steam passed into the water. To keep the pump from moving laterally when it was at work, oak slides, with clamping screws, were attached to the pump, so that they could be pushed out against the sides of the shaft, and then clamped. The spreading of the blocks to which the discharge and

Fig. 1





ELEV·OF· BULKHEAD·
·SHOWING·"OUT-HAUL"·FOR·DUMPING·MATERIAL·
BEFORE·CAGE·WAS·PUT·IN·

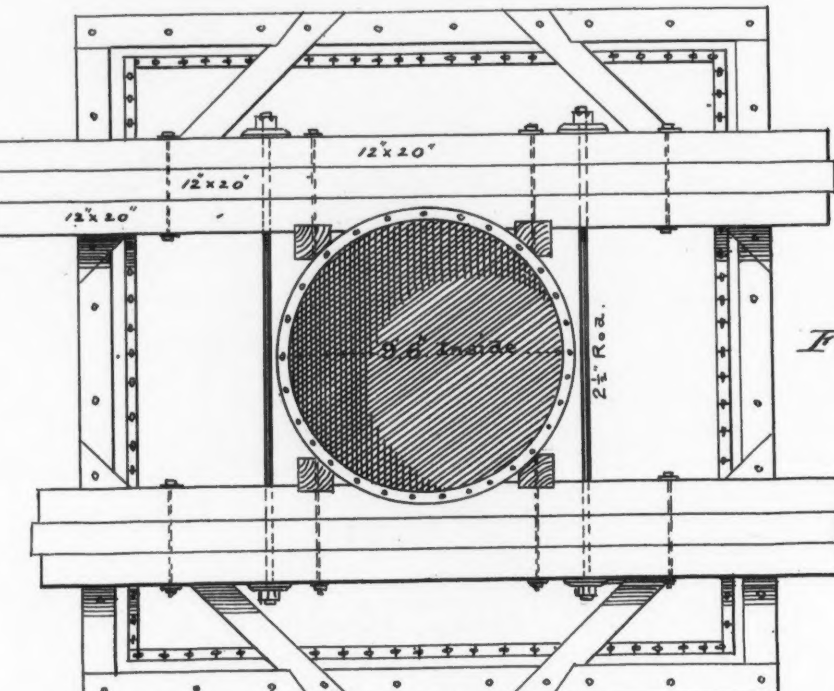
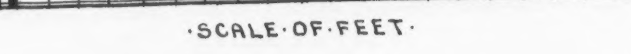


Fig. 2.

PLAN·OF·BULKHEAD·
SHOWING·CYLINDER·CLAMPS·



·SCALE·OF·FEET·

PLATE XLV.
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STAUFFER
ON SHAFT SINKING.

steam pipes were suspended was to overcome the twisting tendency in the falls,

The method of operating this pump was as follows : When the water in the shaft had been pumped down as low as possible, the steam was shut off at the boiler, the top elbow and a 10-feet length of horizontal pipe was taken off from the discharge column, and a 16-feet length added to the discharge vertically. The steam pipe was at the same time being disconnected, at a union provided for that purpose just at the top of the shaft, and a new 16-feet length screwed on ; while this was being done on top, another gang of men, stationed on the pump to prevent twisting in lowering, had hauled in the slides mentioned above. All being now ready for a shift, the engineer lowered the pump slowly, and the men stationed at the discharge and steam pipe ropes allowed these pipes to descend with the pump until the top of the newly added section of steam pipe was just opposite the union ; all ropes were at once secured, connection made with the boiler, and the upper discharge elbow and its pipe again bolted in place, the men on the pump adjusted and secured the slides, and all was once more in position, ready to pump out another 16 feet of the shaft. After the men became expert in their several duties the time required to make a shift was about 25 minutes, computing from the stoppage of the pump to the starting again.

But simple as the above may appear, it was only after repeated trials and failures, and considerable experimenting, that the wished for result was attained. At the east shaft we reached the tunnel grade with our suction pipe 166 feet below the top five several times before we could stay there long enough to pump out the 500 lineal feet of tunnel already driven. It should be remembered that the plunger, as we called it, was only an emergency pump intended to empty the shaft and tunnel preparatory to setting up a large permanent pump of the horizontal type in the tunnel. The vertical pump was troublesome to handle, took up much room with its ropes and pipes, and was difficult to pack.

The steam connection was the most troublesome feature. When the pump was in action there was a very considerable vertical motion due to the elasticity of the fall ropes. This was especially the case when we neared the bottom of the shaft, and a rigid steam connection was consequently impossible. After trying a jointed steam pipe, without

success, we made use of a 6-ply gum and canvas steam hose, 6 feet long, placed between the steam pipe and the steam cylinder on the pump, but, under the steam pressure carried, 100 pounds at the boiler, this hose burst in a few hours ; 10-ply canvas and pure gum was next tried, but even this would sometimes fail, by the intense heat softening the gum and thus allowing the hose to blow off of the iron nipples in the end, in spite of grooves and broad iron clamps, intended to prevent any such accident.

The radiation from the steam pipes, and the ascending steam, caused by water falling on the hot cylinder and pipes, made the temperature in the shaft almost unbearable. This, and the entire want of ventilation in the deep and narrow hole, caused great physical suffering among the men whose duties called them inside, especially when this experience was varied by the bursting of a 2-inch steam hose in the face of the pumpman. To the pluck and endurance of these faithful workmen all success was really due. This 166 feet of shaft was finally pumped out in a little less than nine hours. Having, we hope, given a sufficiently detailed description of how we got into a scrape at the west shaft, and how we finally got out of it, we can now look back and see where we made our mistakes.

First of all, it should have been taken as granted that water was to be met with in abundance, under the circumstances, as we neared the rock. All indications to the contrary, obtained from borings, should have been disregarded. Had this been done, in the opinion of the writer, it would have been ill-advised to have used any form of compound shaft, partly wood and partly iron. The iron cylinders should have been continued to the rock, by using iron rings of reduced height, and cut into four or more segments, put into place at the bottom of the shaft, as soon as the friction prevented the further descent of solid cylinder sections, and the surface water was excluded. The advantages would have been many as compared with the attempt to hang a square wooden shaft to an iron cylinder, the vertical connection would have been continuous and abundantly strong, and the entire shaft could have been made water-tight by caulking the joints with dry pine wedges, or otherwise. And with rings not more than 2½ feet in height, any soft ground could have been passed by a proper system of poling.

It is true that some hanging appliance similar to that finally used might have been at first put into a timber shaft, had the possibility of

meeting water been duly considered by all parties concerned, but the experiment, we think, would have been a dangerous one, as compared with a continuous iron cylinder, and all things considered, it would not have been as economical as iron.

Note.—The Dorchester Bay Tunnel was commenced in January, 1880, and at this date some 4 600 feet of the tunnel are driven. The contract was let to Mr. R. A. Malone, of Pennsylvania ; the writer was engineer for the contractor.

We cannot, in justice, omit the mention of our personal indebtedness to Michael Nolan, who superintended the retimbering of the west shaft, and to William Reardon, the rigger, who put into place our hanging-up appliances. To the pluck, endurance, and practical knowledge of these two men, very much of the success was due.